HTML ABSTRACT

Parity Violating Electron Scattering on the Proton and Deuteron at Backward Angles

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Abstract. The parity violating asymmetry in quasielastic electron scattering from the deuteron at backward scattering angles has been recently measured for the first time. Combined with the previously performed similar measurement on the proton, this measurement provides a determination of both the proton's strange magnetic form factor G_M^s and the axial vector e-N form factor G_A^e. A preliminary analysis indicates that G_M^s is slightly positive but consistent with zero and that $G_A^e(T=1)$ is in substantial disagreement with the theoretical estimate.

INTRODUCTION

The measurement of the neutral weak magnetic form factor of the proton provides an important clue to the quark flavor structure of the nucleon: combined with the known (electromagnetic) magnetic form factors of the proton and neutron, it allows a separation of the proton's magnetic form factor into the three contributing flavors of quarks (up, down and strange) [1]. To the lowest order, the neutral weak magnetic form factor of the proton G_M^Z can be related to the known electromagnetic form factors and a contribution from strange quarks as follows:

$$G_M^Z = (G_M^p - G_M^n) - 4\sin^2\theta_W G_M^p - G_M^s, \tag{1}$$

where G_M^p and G_M^n are the electromagnetic magnetic form factors of the proton and neutron, θ_W is the weak mixing angle, and G_M^s is the contribution from strange quarks. Thus, the measurement of G_M^Z provides unique window to study the role of the strange quark-antiquark "sea" in the electromagnetic structure of the nucleon at low energies.

It is well established that parity violating electron scattering is sensitive to the neutral weak current [2]. Not only is it sensitive to the neutral weak vector current,

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but it is also sensitive to the axial current. Unlike the case of ν-N scattering, in e-N scattering, the axial form factor G_A^e receives an additional contribution from the anapole form factor and can be written as

$$G_A^e = G_A^Z + \eta F_A + R^e, \tag{2}$$

where G_A^Z is the contribution from Z-exchange, η is a constant ($\eta = \frac{8\pi\sqrt{2}\alpha}{1-4\sin^2\theta_W} = 3.45$), F_A is the nucleon anapole form factor [3], and R^e is a radiative correction. The anapole form factor is the parity violating coupling of the photon to the nucleon and is generated at the fundamental level from the weak interaction between quarks in the nucleon. Thus, parity violating electron scattering also provides iteresting and unique information on the axial vector structure of the nucleon.

At the backward angles, the parity-violating asymmetry for quasielastic scattering on the deuteron for the incident electron energy of 200 MeV can be written as

$$A_d = \left[\frac{0.049}{\sigma_d}\right]\left[\frac{-G_F Q^2}{\pi\alpha\sqrt{2}}\right]\left[1 - 0.22 G_A^e(T=1) - 0.10 G_M^s\right]. \tag{3}$$

The similar expression for elastic electron scattering on the proton at 200 MeV is

$$A_p = \left[\frac{0.026}{\sigma_p}\right]\left[\frac{-G_F Q^2}{\pi\alpha\sqrt{2}}\right]\left[1 - 0.24 G_A^e(T=1) - 0.61 G_M^s\right]. \tag{4}$$

G_F is the Fermi coupling constant and α is the fine structure constant. σ_d and σ_p are defined from $\sigma_{(p,n)} = \epsilon(G_E^{(p,n)})^2 + \tau(G_M^{(p,n)})^2$ and $\sigma_d = \sigma_p + \sigma_n$, where ϵ and τ are kinematic factors. The asymmetries are given in units of ppm and the form factors in units of nuclear magnetons. Thus, measurement of both A_p and A_d provides a determination of both the strange magnetic form factor G_M^s and the isovector axial form factor $G_A^e(T=1)$. The contribution from the isoscaler piece of G_A^e, although also uncertain, is small.

The measurement of A_p has been already published [4]. Below, we present our new measurement on A_d and the results from preliminary combined analysis of A_p and A_d.

EXPERIMENT AND RESULTS

The experiment was performed using the SAMPLE apparatus at the MIT/Bates Linear Accelerator Center. The apparatus was essentially the same as in Ref. [4]; the hydrogen target was replaced with liquid deuterium and borated polyethylene shielding was installed between the photomultiplier tubes and the target. This additional shielding was neccessary to reduce the background from neutrons produced in the target from $d(\gamma,n)p$ reactions.

A beam of longitudenally polarized electrons was generated from circularlly polarized laser light incident on a bulk GaAs crystal, accelarated to 200 MeV, and

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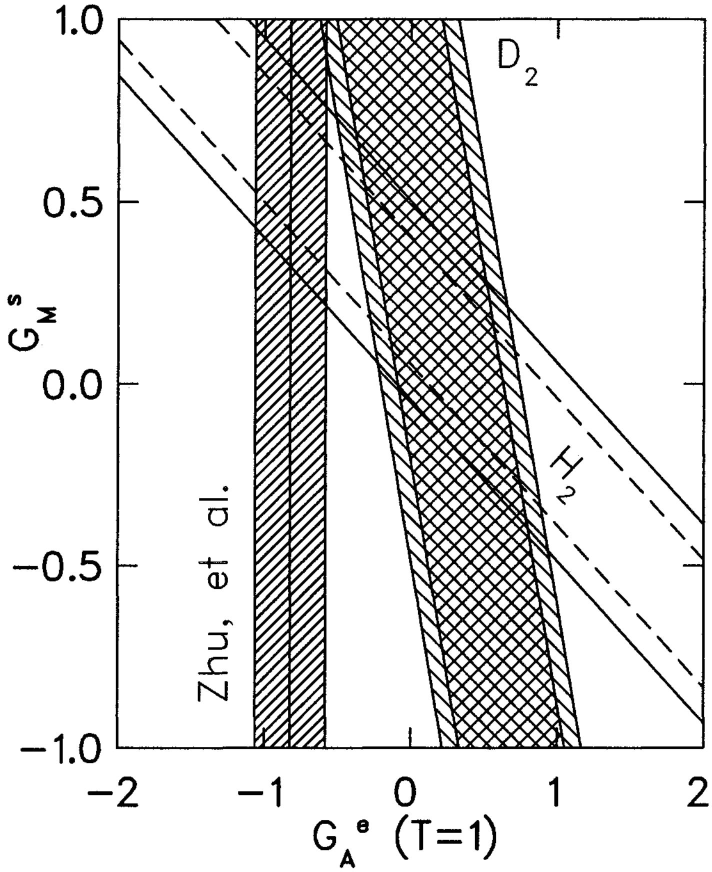

FIGURE 1. A result of a combined analysis of the data from the two SAMPLE measurements. The two error bands from the hydrgeon experiment [4] and the preliminary deuterium experiment are indicated. The inner hatched region includes the statistical error and the outer represents the systematic uncertainty added in quadrature. Also plotted is the estimate of the isovector axial e-N form factor $G_A^e(T=1)$ obtained by using the anapole form factor and radiative corrections of Ref. [5].

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then introduced into the deuterium target. The beam was pulsed at 600 Hz and each pulse had a duration of 25 μs. The helicity of the beam was randomly chosen for each of ten consecutive pulses and the complement helicities were used for the next ten pulses. Electrons scattered at backward angles were detected by ten large solid angle air Čerenkov detectors. The asymmetry in the detector signal yield, normalized to incident beam charge, was computed for pulse pairs separated by 1/60 s to minimize systematic errors due to 60 Hz line noise. The measured asymmetry was corrected for the beam polarization ($\sim 36\%$) and the background dilution factor to obtain the physics asymmetry.

A result of a combined analysis of the data from the two SAMPLE measurements is shown in Fig. 1. The constraints imposed on the values of G_M^s and $G_A^e(T=1)$ from the measured values of A_d and A_p using Eqs. (3) and (4) are shown as error bands. The region where the two error bands overlap provides a determination of G_M^s and $G_A^e(T=1)$. Also plotted in the figure is the estimate of $G_A^e(T=1)$ obtained by using the anapole form factor and radiative corrections of Zhu *et al.* [5].

Prior to running these experiments, the expected value of G_M^s was in the range of -0.5 to 0 [6], and the expected value of G_A^e was $\sim -0.71 \pm 0.20$ as a result of substantial modification due to the anapole term and the radiative correction [7] (their recent update in Ref. [5] gives a consistent value). The experiments indicate a rather different picture as shown in Fig. 1. The best value of G_M^s appears to be slightly positive, consistent with zero, and the best value of G_A^e indicates that the substantial modifications of G_A^e predicted in Refs. [7,5] are not only present, but probably with an even larger magnitude. From a theoretical standpoint, the most uncertain contribution to G_A^e is from the anapole term and the experimental results can be interpreted as an unexpectedly large anapole form factor of the nucleon.

Clearly the situation warrants further theoretical study as well as additional experimental investigation. It is expected that a new measurement of parity violating quasielastic electron-deuteron scattering at lower energy [8] will provide an improved determination of $G_A^e(T=1)$ as well as G_M^s.

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